WATER QUALITY OF RUNOFF AND LEACHATE FROM AN IMPROVED DAIRY LOAFING AREA

K. A. McVay[1] and D. E. Radcliffe[2]

AUTHORS: [1]Graduate student and [2]Professor, Department of Crop and Soil Sciences, University of Georgia, Athens, Georgia 30602.
REFERENCE: Proceedings of the 1999 Georgia Water Resources Conference, held March 30-31, 1999, at the University of Georgia. Kathryn J. Hatcher, editor, Institute of Ecology, The University of Georgia, Athens, Georgia.

Abstract. To lessen soil erosion due to high animal stocking rates on small Georgia dairies, the Natural Resources and Conservation Service (NRCS) recommends a system that utilizes geotextile material covered with crusher run gravel as a soil cover in high animal traffic areas. Soil erosion is dramatically reduced, yet due to the large accumulation of manure, questions remain concerning water quality with these systems. At a 120 cow dairy in Oglethorpe county Georgia, a loafing lot utilizing this system was constructed on a Pacolet sandy loam soil (clayey, kaolinitic, thermic, Typic Kanhapludult). Runoff water and leachate were characterized by storm events for water balance and chemical information. Surface runoff water typically contained levels of NH_4-N, and PO_4-P that exceeded EPA guidelines for surface water. Sub-surface drainage intercepted by tile drains had NO_3-N levels ranging from 10 to 40 ppm exceeding the EPA drinking water standard. It is recommended that surface water running off improved loafing lots either be routed to a wastewater lagoon for irrigation, or to adjacent hay fields to reduce the impact of excess nutrients to surface waters.

INTRODUCTION

The University of Georgia Cooperative Extension Service (CES) in cooperation with the USDA Natural Resources Conservation Service (NRCS) sampled 138 rural wells during the period from June, 1991 to October, 1992. Seventeen percent of the wells on farms had nitrate concentrations in excess of the EPA standard of 10 ppm while only 5% of non-farm wells exceeded this limit (Gould, 1993).

In the summer of 1994 eight dairies were surveyed in an attempt to identify the source of nitrate contamination (Drommerhausen et al., 1995). Electrical conductivity measurements were used in transects radiating from wellheads. This rapid, non-intrusive method can identify areas of high soluble salts in soils. In every case, high readings were found in the dairy loafing lots. These lots are the unpaved areas leading to the milking shed where cows congregate prior to milking and many times remain overnight. Although the herd spends as much time in these areas as in the milking shed, no system is in place for handling the waste that accumulates in these loafing lots. The large number of cows in these relatively small areas has resulted in waste deposition rates that cause high subsurface loses of nitrate and other soluble salts common in manure. Wells located close to these lots could be contaminated. Surface runoff has the potential to contaminate nearby surface waters with increased levels of nitrogen and phosphorus.

One solution to the problem would be to pave these areas with concrete (about $1.50 per square ft) so that manure could be flushed to a lagoon. A more economical and easily managed solution could be the installation of a permeable synthetic geotextile fabric covered with about 15 cm of crusher run gravel. The North Carolina NRCS pioneered the use of these materials around beef cattle feeding areas and walkways and the Georgia NRCS has extended it to loafing areas at dairies. The intention of this program is to reduce surface erosion and keep these areas from becoming a bog in the winter. The cost of installation including materials and labor is about $0.55 per square ft. Solid build-up on the surface has been slow and has been controlled by scraping about once a year. There is a need to assess the impact to the environment of potential runoff losses and subsurface losses of nutrients from this system.

The objective of this study was to install and monitor a system of buried drains and gravel covered surface geotextile fabric in the loafing lot of a dairy farm. Runoff water and subsurface drainage would be routed to the existing lagoon of a participating farmer.

MATERIALS AND METHODS

An improved loafing lot, designed by the engineering staff of the Natural Resources and Conservation Service, Watkinsville, GA., was constructed at the Alan Bridges dairy in Oglethorpe County Georgia. Approximate dimensions were 20 m by 40 m, with perforated plastic drain lines placed on 7.5 m centers under the entire area. The area was designed for a herd size of 40 cows. Drain lines were placed at a depth of 0.9 m below the soil surface in a 30 cm bed of no. 60 gravel. All lines were connected to a common header that discharged into a sump for flow measurement and periodic sampling. The soil above the drain lines was mechanically repacked to prevent preferential flow to the drains. Surface water was routed by earthen berms to a 7.6

cm parshall flume for flow measurement and automated sampling. The construction of the berms resulted in the removal of most of the surface soil in the loafing lot. The remaining surface of the lot was smoothed, covered with a geotextile material, then covered with 8 cm of crusher run gravel, and an additional 7 cm of granite dust. Water samples were obtained during storm events by an ISCO refrigerated sampler and held at 4 C until collection. Samples were collected and processed usually within one week of an event. Soil samples were obtained in increments to a depth of 1.5 m below the soil surface at the establishment of the lot and after 1.5 years of operation. Soil samples were analyzed for extractable nitrate, ammonium, chloride, and phosphorus for both sampling dates. Storm water samples were filtered through 45 μm filters and then analyzed for soluble nitrate, ammonium, phosphorus and chloride.

In an area adjacent to the loafing lot an instantaneous profile measurement was conducted during the summer of 1998 to help quantify unsaturated flow in the soil beneath the loafing lot. The experiment consisted of a 1 m by 2 m square undisturbed block of soil approximately 1.2 m in depth. Soil horizons were described and time domain reflectometry rods were inserted horizontally into the center of each horizon to measure volumetric water content. Tensiometers were placed at the intersection of each horizon to measure hydraulic gradients across the horizons. The exposed soil on the faces of this block were sealed using liquid saran and then waterproofed to prevent flow through the walls of the block. Reinforced concrete was placed around the block and then the remaining area was backfilled with soil. The soil block was left exposed to natural rainfall and drainage for the winter of 1997 and spring of 1998. In June of 1998 grass in the surface of the block was clipped and chemically killed and a 3 cm pond of water was established to saturate the profile. After saturation, the surface of the block was sealed with plastic sheeting, and allowed to drain. Water content was automatically recorded hourly for 109 days and tensiometers were read periodically throughout the study as the profile drained.

During excavation around the soil block, intact soil cores from each horizon were obtained and taken to the lab for determination of moisture release, saturated hydraulic conductivity, and particle density. Using inverse mathematical methods, prediction of unsaturated hydraulic conductivity from the intact cores was compared to the measured unsaturated hydraulic conductivity of the soil block in the field.

RESULTS

Water Balance

Sixty-seven separate runoff events were documented between February 8, 1997 and September 3, 1998. Although the magnitude of each event varied depending on rainfall duration, intensity, and time since a previous storm, a typical hydrograph is depicted in figure 1. Rainfall and runoff were recorded on 5 minute intervals, and runoff occurred with very little delay following rainfall events. For this particular event, runoff was 38.8% of total rainfall. Tables 1 and 2 summarize total amounts of runoff by month for both years.

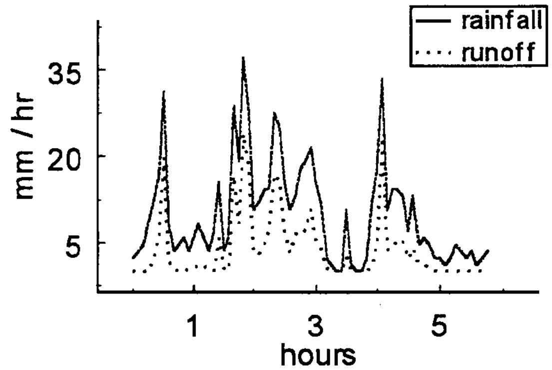


Figure 1. Hydrograph for storm on April 27, 1997 Bridges dairy, Oglethorpe County.

The range of runoff for 1997 varied from 5 to 26% of total rainfall for the period, with an average of around 14%. For 1998 the range was 0 to 30% with an average of 18%. Sub-surface drainage captured by the tile drain was less than 1% in nearly all cases.

The 15 cm rock mulch on the surface of the soil nearly eliminates evaporation, and very little vegetation survives on the lot making transpiration negligible. Surface runoff and tile drainage together account for less than 20% of annual rainfall. Temporary storage followed by subsequent drainage could result in 80% of annual rainfall impacting ground water. To test this assumption, a two-dimensional finite-difference model was used to check the amount of drainage that would be expected to be intercepted by tile drains for a typical storm.

Table 1. Water Balance For Each Month in 1997 at Bridges Dairy, Oglethorpe County.

month	rain	tile drain	runoff
	mm		
Feb	198.1	*	40.0
Mar	68.8	*	18.3
Apr	139.2	*	36.1
May	88.2	0.003	19.0
Jun	64.5	2.478	12.9
July	88.6	*	3.6
Aug	42.1	*	3.0
Sep	144.3	*	19.8
Oct	127.8	*	27.4
Nov	76.8	0.203	4.2

* not monitored during this period

Table 2. Water Balance For Each Month in 1998 at Bridges Dairy, Oglethorpe County.

month	rain	tile drain	runoff
	---------------- mm ----------------		
Jan	29.6	0.269	*
Feb	87.1	0.463	26.3
Mar	112.6	0.278	33.7
Apr	174.5	0.850	37.2
May	78.9	0.503	23.3
Jun	61.4	0.094	0.0
July	36.6	0.094	4.6
Aug	43.9	0.025	0.1
Sep	80.8	0.006	0.9
Oct	19.0	0.000	0.3

* not monitored during this period

Table 3. Chemistry of Runoff Water Exiting Loafing Lot Averaged for Each Month, Bridges Dairy, Oglethorpe County.

Date	NO3-N	NH4-N	PO4-P	Cl	reps
	---------------- mg kg^{-1} ----------------				
Bkg	1.1	0.5	0.0	10.6	25
Sep-97	8.7	2.3	10.8	24.9	17
Oct-97	4.4	1.4	8.1	23.7	19
Nov-97	0.1	26.3	8.8	142.1	16
Dec-97	0.1	26.1	10.0	165.3	5
Feb-98	1.6	11.3	8.3	46.0	16
Mar-98	34.7	11.4	15.6	*	7
Apr-98	39.4	2.5	10.4	*	21

* measurement not completed

The model storm had a 0.5 cm hr^{-1} rainfall rate that lasted 30 hours followed by a 70 hour drainage period. The simulation was run twice. The first run started with a uniform soil tension of –50 cm H_2O throughout the profile with a constant –50 cm H_2O boundary condition at the bottom of the simulation zone. Water was allowed to flow out only through the bottom face. The second run used the same initial and boundary conditions, but included a seepage face to simulate the loss of water through tile drain. Figure 2 shows the output from the two simulations.

The difference between the two graphs is the effect of the tile drain (Figure 2). After approximately 60 hours, the two curves proceed at the same rate. The difference between the two at the end of the simulation is 0.793% of the rainfall amount. This is the amount expected to be recovered by the tile drain, and it is similar to the amounts indicated in Tables 1 and 2 for tile drain on a monthly basis.

For the year 1998 where tile drain measurements are more complete, the percentage of days water was flowing into tile drains was 13% of the days monitored. Assuming that during this period water was also flowing to groundwater at saturation, then 50% of the annual rainfall could be accounted for by the effective hydraulic conductivity of the upper 1.2 m of soil. Tile drains only recover water when the soil is saturated. It isn't unreasonable to assume that unsaturated flow during the other 87% of the time could account for the remaining 30% of annual rainfall. Therefore, on an annual basis 80% of annual rainfall could be impacting groundwater under the loafing lot.

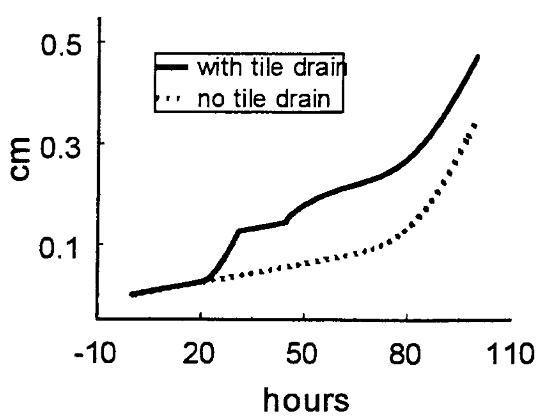


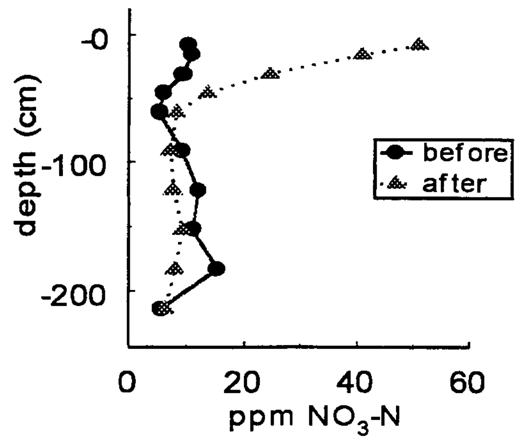
Figure 2. Cumulative flow out of the profile and tile drain under two different boundary conditions for the simulation.

Water Chemistry

Monitoring of water from runoff events began on February 13, 1997 prior to confining livestock in the loafing lot. Cattle were not in the loafing lot until September 1997. At that point the farmer placed approximately 60 cows in the lot for two to three months, and then only on an irregular basis after that. Samples prior to September, 1997 had very low levels of ammonium, phosphorus, nitrate, and chloride (Table 3). Once the cattle were confined to the lot, all analytes immediately increased in concentration. Phosphorus and ammonium were exceedingly high for waters released to the environment. Nitrate levels remained below the 10 ppm EPA limit for drinking water until the spring of 1998 when

Table 4. Chemistry of Tile Drain Water, Bridges Dairy, Oglethorpe County.

date	NO3-N	NH4-N	PO4-P	Cl
	---------------- mg kg^{-1} ----------------			
13-Feb-97		0.1	0.0	6.8
29-Apr-97	5.9	0.1	0.0	11.8
25-Sep-97	5.3	0.0	2.0	50.2
26-Sep-97	60.4	0.0	0.3	109.0
18-Nov-97	46.0	0.7	0.5	95.3
26-Nov-97	40.8	3.8	1.3	98.1
6-Feb-98	40.5	1.4	0.2	52.4
11-Feb-98	37.0	0.9	0.7	56.2



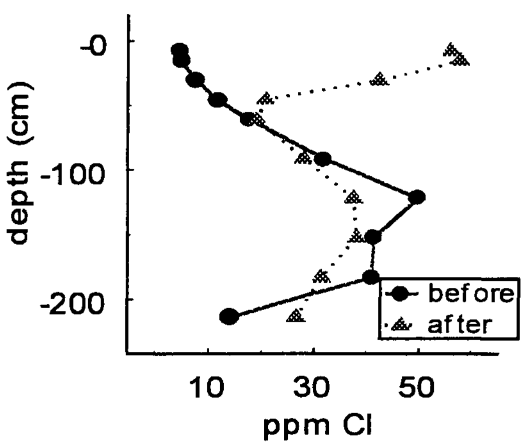


Figure 3. Distribution of soil nitrate and chloride in soil beneath the loafing lot, Bridges dairy, Oglethorpe county.

temperatures were high enough for mineralization to occur. Water removed by the drain tile had a different chemical signature than that of surface water (Table 4). The arrival of higher levels of nitrate coincides with the time that the cattle were allowed into the loafing lot. Phosphate concentrations are also elevated above their background levels of April 1997.

Soil Chemistry

The distribution of soil nitrate and chloride changed by the addition of cattle to the loafing lot (Figure 3). A significant increase in nitrate and chloride near the soil surface is evident. The presence of higher levels of chloride at depth is likely a relic of a previous deposit. The existing chloride peak located at around 1.2 m did not move over the two years that passed, but did decline in concentration from 49 ppm to approximately 38 ppm. Extractable phosphorus was reduced in the soil beneath the loafing lot over the period of the study (Table 5). This could be due to greater fixation

Table 5. Extractable Phosphorus and Ammonium in the Soil Beneath the Loafing Lot Before and After Periodic Confinement of Cattle, Bridges Dairy, Oglethorpe county.

depth	PO4-P		NH4-N	
	before	after	before	after
-- cm --	ppm			
7.6	15.38	3.75	1.72	3.01
15.2	3.66	0.67	1.29	2.12
30.5	1.07	0.61	0.64	1.24
45.7	0.87	0.58	0.46	0.28

of phosphorus on clays and iron oxides, or could be a result of increased soil pH. Further analysis is required to determine the exact cause of this change. Extractable soil ammonium levels increased in the upper 30 cm reflecting the input from manure additions in the loafing lot.

CONCLUSIONS

Approximately 20% of the annual rainfall can be expected to be removed as surface runoff from improved dairy loafing lots. If the lot is being used for confinement of livestock, the soluble phosphorus and ammonium content of this water would be high enough to warrant impoundment in a lagoon, or controlled discharge onto an adjacent hayfield for crop uptake. The impact to groundwater is as great a concern, as high levels of nitrate apparently mineralize in the soil beneath the loafing lot, with a majority of the annual rainfall moving this nitrate toward ground water. The rock and geotextile successfully prevented the formation of a bog in winter.

ACKNOWLEDGMENT

This research was supported in part by EPA 319 funds in cooperation with the Georgia Soil and Water Conservation Commission.

LITERATURE CITED

Drommerhausen, D. J., D. E. Radcliffe, D. E. Brune, and H. D. Gunter. 1995. Electromagnetic conductivity surveys of dairies for groundwater nitrate. J. Environ. Qual. 24:1083-1091.

Gould, M. C. 1993. A summary of nitrate levels in well water samples. Water Quality Courier: A Newsletter on Water Quality Issues. 2:3-4.